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A Bed Sediment Sampler for Precise Depth Profiling of Contaminant Concentrations in Aquatic Environments

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ABSTRACT

A bed sediment and detritus sampler has been developed for use in aquatic environments, such as in canals, rivers or lakes, for determining precise depth profiles of contaminants. The device is superior to currently available commercial push-tube and piston samplers in its simplicity, ease of use and its ability to retrieve and extrude sample cores. The sampler has been used with success during the past 12 mo to determine a profile of bed sediment Se concentrations within an earth-lined canal, alternatively used for conveyance of agricultural drainage and wetland water supply.

PRECISE DEPTH sampling of the near surface sediments of lakes, pools, streams, rivers, and canals is important for the monitoring of contaminant fate and transport. Often a loose, gelatinous layer of detritus lies at the sediment/water interface, which is either lost or substantially disturbed with typical core samplers. The detrital layer is typically more biologically active than bed sediments sampled at greater depths and is of great importance in assessing the bioavailability of Se, an area of intense research interest in the San Francisco Bay-Delta of California. The bioavailability of Se is influenced by Se species and is determined by the source of the contaminant, its mode of accumulation in the sediments and by redox potential. Selenium is found in oil refinery product water and in agricultural drainage water from the west side of the San Joaquin Valley, all of which discharge into the Bay-Delta. Accurate determination of the depth distribution of the various Se species within the sample is essential to make progress in this area of research. This requirement led to the development of the improved bed sediment sampler described in this paper.

Commercially available push-tube and piston samplers from limnological supply companies consist of metallic or acrylic tubes that are sometimes equipped with a stopper that is displaced as sediment is forced into the tube (Forestry Suppliers Inc., 1996). The stopper helps to keep the sediment core within the tube while the sampler is withdrawn through the water column. The major problems encountered with this type of sediment sampler for contaminant profiling are the difficulty in controlling the depth of sampling and difficulty in extruding the sediment core from the sampler barrel in precise depth increments.

In the case of a typical push-tube sampler, if the stopper is designed to retract during insertion of the barrel into the bed sediments, loose material and detritus at the water/sediment interface may be displaced from the barrel opening, eluding capture. If the stopper is retracted prior to insertion, a column of water is collected together with the bed sample, the weight of which can displace the plug of sediment from the tube once it is lifted out of the water. Blomqvist (1991) noticed that disturbance of surface sediments during collection of samples was greater when wide push-tube samplers were used than with narrow push-tube samplers.

Mixing of the bed sediment sample or loss of the detrital layer can be difficult to avoid while decanting the column of water from the push-tube. If the bed sediment sample has high clay content and is sticky, extrusion is difficult without the use of a plunger or piston. Most stoppers are designed to seal at the top of the push-tube and cannot be used to extrude the sample core from the barrel of the sampler in precise depth increments.

Since many push-tube and piston samplers are made of metal it is not possible to observe the sample in its original orientation, to see the volume of detrital material associated with the sample, or to notice any mixing that may occur upon extrusion. The piston sampler designed by Wright (1967) suffers from this problem. Fisher et al. (1992) describe a simple and inexpensive piston sampler made of clear polycarbonate that overcomes this deficiency but which requires the use of separate extruder rod to remove the sample from the push-tube. This requires that the push-tube to be inverted and the extruder rod to be driven into the ground—a time consuming task and a procedure that might compromise sampling precise depth increments of the bed sediment.

A computer search made on the World Wide Web produced several commercial piston samplers produced by a Aquatic Research Instruments Inc. (1997). These samplers are similar in design to Fisher et al. (1992) and employ the same crude technique for extruding the samples from the push-tube. The size and complexity of this sampler would appear making it more suitable for deployment from a boat, with the aid of a winch, for use in limnological sampling of lakes and deep rivers.

MATERIALS AND METHODS

The sediment sampler developed at Lawrence Berkeley National Laboratory (LBNL) is a push-tube device that has been modified to overcome many of the problems noted pre-

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viously. First, a clear lucite tube is used for the barrel of the sampler, through which the sample can be observed (Fig. 1). Within the tube, a tightly sealed rubber plunger and check valve assembly are used for four purposes: (i) as the tube is pushed into the soil, water is displaced through a check valve so as not to pressurize the sample in the tube; (ii) as the sample barrel is extracted from the sediment bed, the check valve is closed, creating a vacuum that holds the sample in place; (iii) upon being withdrawn from the water column, the sample can be observed through the lucite tube. Once clear of the water the end of the sampler barrel is capped, the check valve is opened once again and the caulking gun trigger is pumped to move the plunger through the layer of water above the detrital layer at the bed sediment/water interface. This water is pumped through the check valve until all of the unwanted water has been decanted and; (iv) the check valve is then closed manually, the sampler inverted and the caulking gun plunger is again used to extrude the sample from the lucite tube until the plunger lines up with one of a series of depth markings inscribed on the barrel.

Since contaminant concentrations are measured in mass per volume this device is capable of very precise and repeatable volume samples of bed sediments and has potential to improve the utility and comparability of sediment contaminant data. The device has been tested in sediments ranging in composition from very loose silts to moderately compacted sandy clays and has worked consistently well.

DESIGN AND FABRICATION

The bed sediment sampler is fabricated using a 400-mm long piece of clear lucite tubing that is fitted on to a 635-mm long aluminum tube with a 75-mm overlap (Fig. 1). The internal diameter of the lucite tubing is 50 mm, which provides sufficient sample volume for analysis. The aluminum tube is machined with a slot along its length to allow the pumping mechanism of a commercially available caulking gun to be inserted. When the lucite tube is slipped over the aluminum tube, it rests firmly against the pumping mechanism. These three components are held tightly together using two hose clamps. The caulking gun is modified such that its pump rod is replaced by a 500-mm long, 12.5-mm diam. aluminum pump rod. At one end of this rod is a rubber plunger and check valve assembly while at the other end is a lever mechanism that operates the check valve with the release of a stainless steel cable.

The rubber plunger is made by slicing a 10-mm section of a typical neoprene laboratory stopper. A stainless steel disk of smaller diameter than the rubber is placed on either side to provide support. Two holes are drilled through the stopper and disks and a 1.6-mm thick neoprene membrane is used as a "flapper" type check valve, seating against the disk on the narrow side of the stopper. The four pieces are joined through the center with a machine screw and nut so that the plunger is a single, removable assembly. The threads of the screw protrude through the plunger on the narrow side so as to allow it to be easily threaded into the end of the pump rod.

On the pump rod, a beveled plunger made of 10-mm PVC pipe is used to manually disable the check valve. The wide end of the piece has a diameter equal to the width of the flapper. The narrow end has a diameter slightly larger than that of a spring that pushes the PVC plunger against the flapper, preventing water from escaping through it. The other end of the spring is fixed in position with a roll pin inserted through the rod. A stainless steel cable attaches the beveled PVC plunger to a lever assembly at the top of the pump rod.

The retraction mechanism for the beveled PVC plunger consists of a small aluminum block and lever. The block has a hole bored through it such that it slips over the pump rod. A set screw in this block allows it to be firmly fixed to and removed from the pump rod. Cable tension is adjusted by repositioning the block. The lever is attached to the block with a machine screw, which also acts as the pivot. The lever shape and the cable attachment design is such that the spring holds the lever in both the open and closed positions. The lever extends through the sampler body from the slot milled along the aluminum barrel. The length of the slot is approximately equal to the stroke of the caulking gun mechanism. Figure 1 shows the lever in the upward locked position, and the beveled PVC plunger fully retracted from the flapper valve. Figure 2 shows the lever in the same position as the sampler is raised from the channel after being pushed into the bed sediments.

A second lever is shown in Fig. 1 and 2, aligned at right angles to the aluminum tube and fixed to the pump rod immediately below the beveled PVC plunger lever pivot. This lever allows the rubber plunger and check valve assembly to be retracted together inside the lucite barrel, usually to a position that is a few centimeters greater than the approximate depth of the bed sediment sample. This operation can only be performed when the caulking gun pump mechanism has been disengaged—this is accomplished by twisting the caulking gun push rod through 180 degrees from the upright, fully engaged, position.

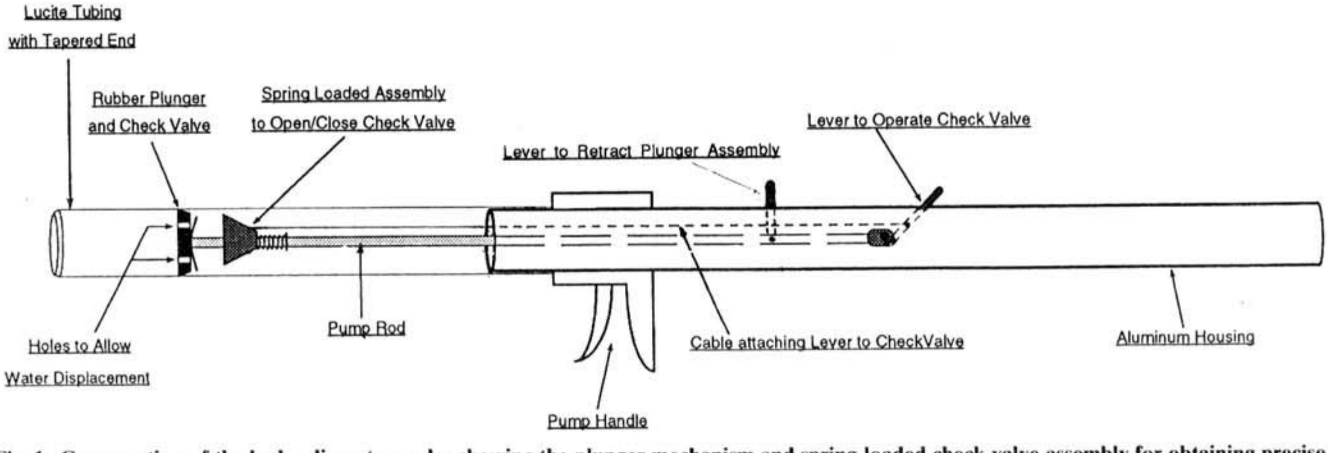

Fig. 1. Cross-section of the bed sediment sampler showing the plunger mechanism and spring-loaded check valve assembly for obtaining precise volume samples.

Fig. 2. Technician using the bed sediment sampler to obtain a profile of Se concentrations in canal sediments in the western San Joaquin Valley, California.

SAMPLING PROTOCOL

The bed sediment sampler is pushed into the canal or stream-bed with the plunger in the fully retracted position and with the check valve open. As the sample push-tube moves into the bed sediment, water is displaced through the check valve. After reaching the maximum sample depth within the sediment and prior to extracting the push-tube, the check valve is normally closed by releasing the lever, creating a vacuum, which holds the core sample in place. When brought to the surface, the sample is visible through the lucite tube. In the Bay-Delta a multicolored sediment plug appears in the push-tube with a gelatinous detrital layer at the sediment/water interface and a layer of clear overlying water (Fig. 2).

The sampler is held vertically, with the push-tube capped, to prevent sediment from escaping, while the caulking gun trigger is pumped to displace the water column above the detrital layer. The check valve lever should be retracted, during dewatering, which opens the check valve and allows water to pass through the holes in the valve. When the boundary between the detrital layer and the overlying water is reached the check valve lever is released, the valve closed, and the core sample extruded from the tube until the plunger is aligned with one of the sediment depth markings on the lucite push-tube.

Although with many bed sediment samples, especially those with high clay content, it is possible to extrude the sample from the push-tube in this downward pointing attitude, it was found to be preferable to invert the sampler so that the push-tube aperture pointed upwards. This has the advantage of improving the alignment of plunger and the depth markings leading to a more precise volume sample and avoids inadvertent loss of sample. No mixing of the top sediment and detrital layers was observed when collecting samples in the 0 to 30 mm and 30 to 80 mm bed sediment depth ranges.

To obtain samples from deep channels, poles of various lengths can be clamped onto the sampler barrel. For deep water sampling, where attaching a pole would be impractical, the sampler could be attached to a cable and weighted to collect a sample. In cases where the detrital layer is not of importance and where sediments are sufficiently compacted and cohesive to force the plunger to retract when inserted, the plunger may be started in the end position with the valve closed. Additionally, if sample analysis may be affected by the metal parts used in the assembly, other materials such as PVC or fiberglass could easily be used in place of the metal components. Sampler dimensions could also be changed to accommodate various sampling depths.

Table 1. Demonstration of sampling precision using the bed sediment sampler to obtain a sediment Se profile in the tidal estuary in San Francisco Bay, California.

	Sample depth, 0–30 mm	Sample depth, 30–80 mm
	mass, g	
1	22.98	46.44
2	24.87	51.02
3	25.40	48.93
4	18.60	39.45
5	21.79	50.56
6	24.38	48.81
7	23.27	47.21
8	26.43	60.86
9	23.09	48.43
10	24.68	42.11
Mean	23.55	48.38
SD	2.28	5.93

EXPERIMENTAL RESULTS

An experiment was conducted in San Francisco Bay at Point Richmond, CA, to assess the precision of the sampler in obtaining bed sediment samples for Se analysis. Selenium is a redox sensitive that is adsorbed and immobilized in bed sediments. Several factors determine the depth distribution of Se in sediments including pH, redox potential, bed hydraulic gradient, organic matter content, and clay content of bed sediments. Under ponded water conditions, Tokunaga et al. (1995) have determined that the highest Se concentrations occur in the top 30 mm of the bed sediments.

The sampler was used to obtain 10 bed sediment samples at Point Richmond using the technique described previously. After extracting the push-tube from the bed sediment the sample was dewatered through the check valve until the plunger was aligned with the water/sediment interface. The check valve was then closed by releasing the cable lever, the sampler inverted, and the sediment sample pumped out until the sampler plunger lined up with the first etched mark on the barrel (80 mm). A knife was used to slice the sample flush with the mouth of the sampler barrel and then the caulking gun trigger was pumped to transfer the contents of the barrel into a metallic sample container, of known weight, until the plunger was aligned with the second etched mark (30 mm). The sample was again sliced and the trigger depressed until the plunger emerged from the end of the barrel transferring the barrel contents into a second container. Care was taken to scrape any attached sediment from the face of the plunger.

The samples in the metallic containers were oven dried at 104.5°C for 48 h after which the containers were reweighed and the sediment mass from each determined. Table 1 shows the results from the experiment conducted on San Francisco Bay sediments. Standard deviations from the mean values of 2.27 and 5.93 g were calculated using the Microsoft Excel spreadsheet package for the sediment depth ranges of 0 to 30 mm and 30 to 80 mm, respectively.

SUMMARY

A bed sediment and detritus sampler has been developed for use in aquatic environments such as in canals, rivers, or lakes for precise depth measurement of contaminants. The device is superior to currently available commercial underwater samplers in its ease of use, ability to retrieve sample cores and measure contaminant concentrations at precise depths. An experiment conducted with the sampler with heterogeneous sediments at Point Richmond in San Francisco Bay showed that the sampler was capable of achieving a precision of +/−10%. The ability to discern the depth distribution of Se and other chemical species in bed sediments is critical to the success of environmental monitoring and cleanup efforts not only in the San Francisco Bay-Delta but in other sensitive ecosystems in the USA and around the world.

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